A detailed look at the cumulus-valve mechanism and its potential implications for cloud-base cloudiness

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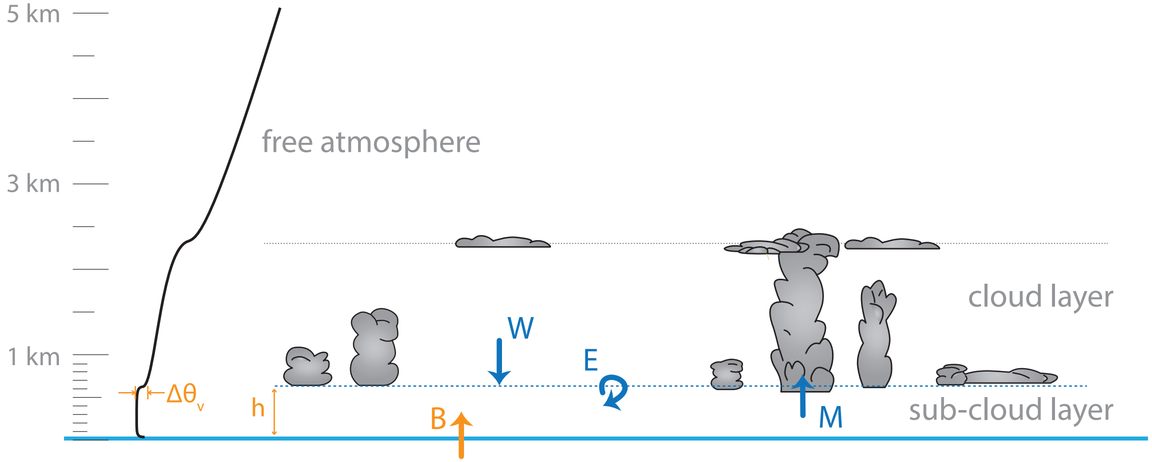


Uncertain warming response of cloud-base cloudiness in trades

Discrepancy in warming response between GCMs and Large-eddy simulations (LES) near cloud base, where cloud amount largest *(Vial et al. 2017, Nuijens et al. 2014)*

> GCMs: very sensitive to warming, controlled by convective mixing *(Sherwood et al. 2014)*

> LES + Observations: largely insensitive *(Bretherton et al. 2013, Nuijens et al. 2014, Vogel et al. 2016)*

$$\frac{Dh}{Dt} = E + W - M$$

$$M = a_{co} \cdot w_{co}$$

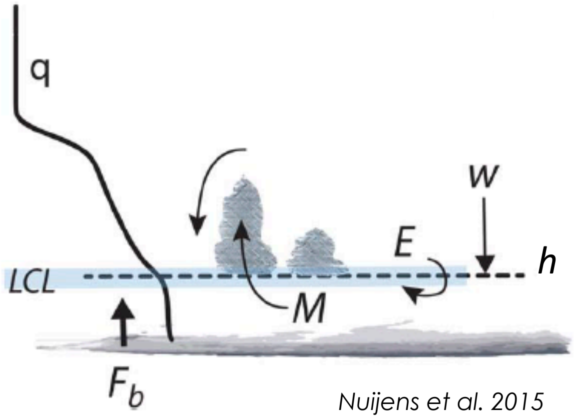
Cumulus-valve mechanism:

> convection acts like a valve that maintains the mixed-layer top *h* close to the lifting condensation level (LCL) *(Betts 1976, Albrecht et al. 1979, Neggers et al. 2006)*

> negative feedback on humidity, and pot. cloudiness near cloud base *(Neggers et al. 2006, Nuijens et al. 2015)*

> could explain larger cloud fraction with increasing mass flux

→ **opposite to what many GCMs do**



Nuijens et al. 2015

purpose:

Use ICON-LEM simulations to study the premises of the valve mechanism and its potential implications for cloud-base cloudiness

research question:

Does cloud-base cloudiness increase with increasing mass flux?

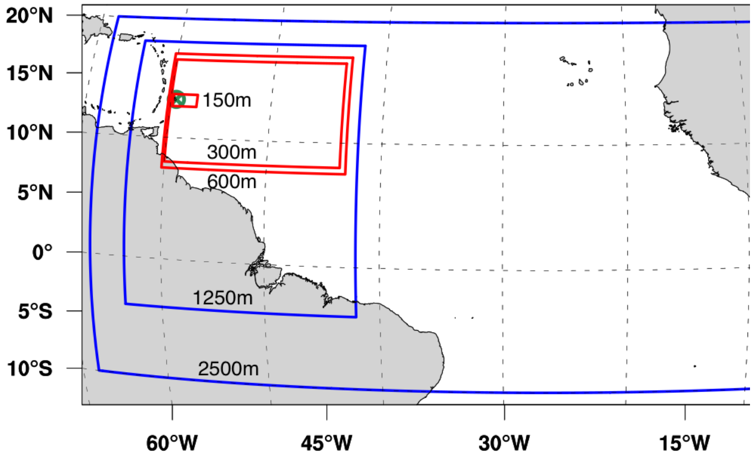
ICON-LEM simulation over tropical Atlantic

> ICON-LEM simulations run by Matthias Brueck at MPI

> Smagorinsky turbulence, binary cloudiness, fixed SST

> initialization and lateral boundary conditions from ECMWF IFS (nudged every hour)

> 150m, 300m & 600m resolution, 155 vertical levels



(from Matthias Brueck)

used here:

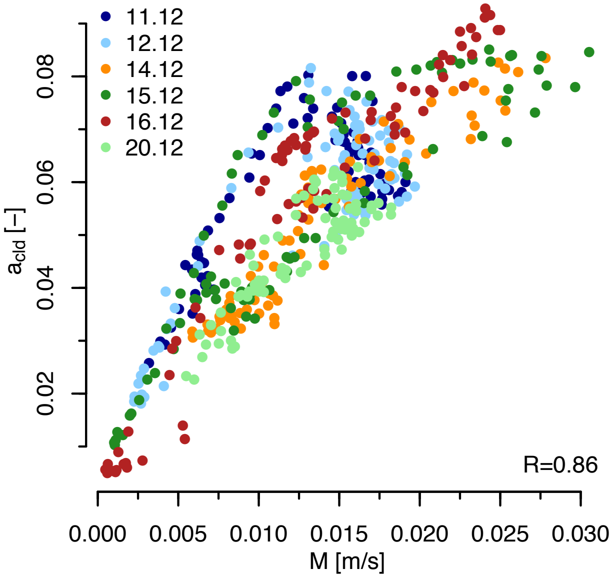
> 150 m resolution on 1° x 2° domain upstream Barbados

> 6 days in December 2013, from 12 LT – 8 LT

Does cloud-base cloudiness increase with increasing mass flux?

Mostly yes...

$$M = a_{co} \cdot w_{co}$$



> The mass flux M explains a lot of the variations in cloud-base cloud fraction (a_{cld})

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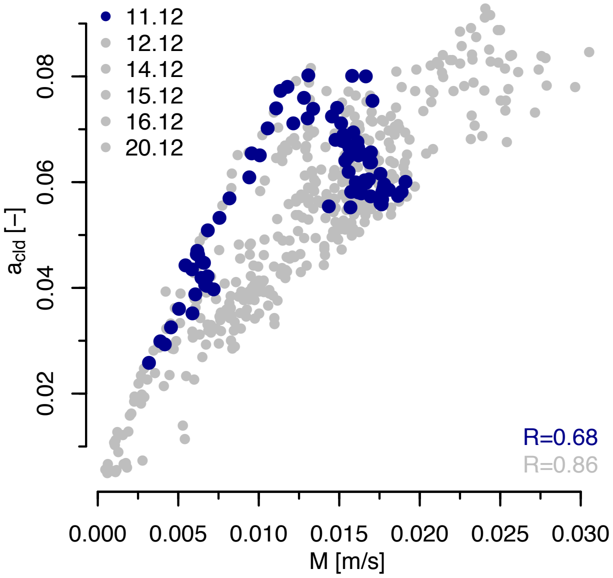

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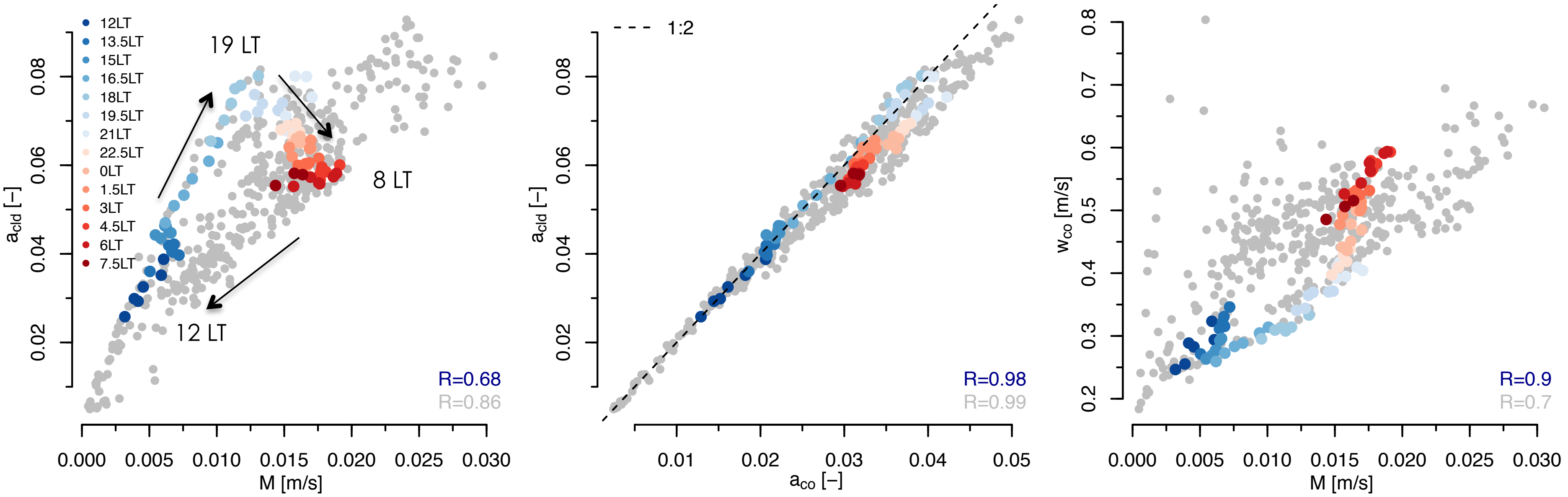
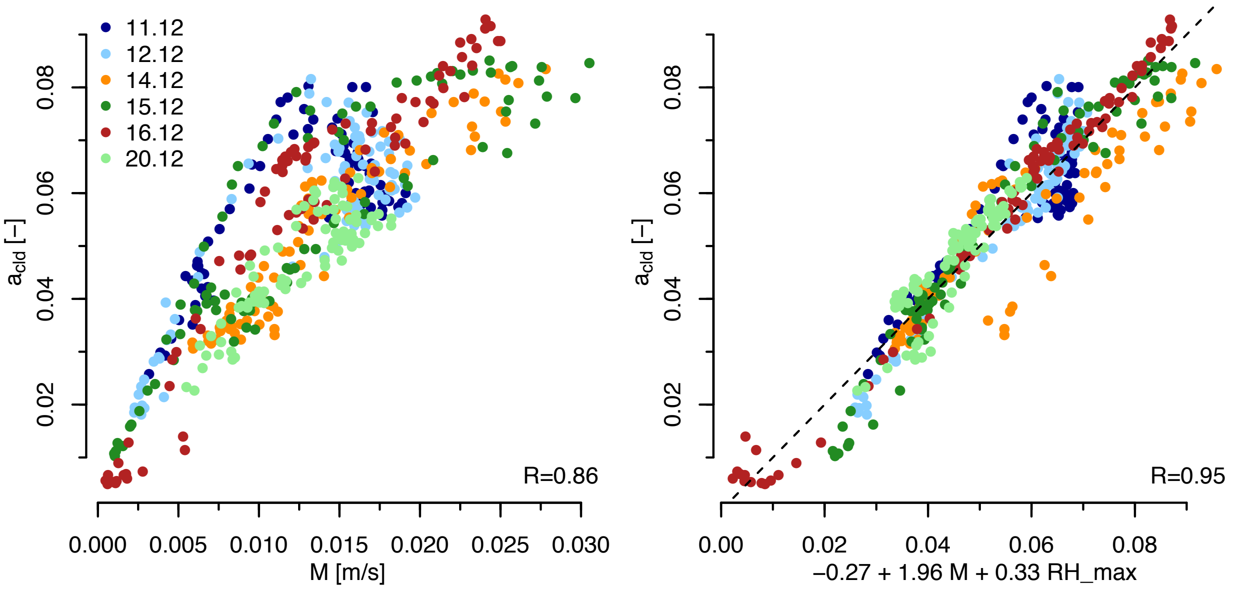


> The mass flux M explains a lot of the variations in cloud-base cloud fraction (a_{cld})

> Positive daytime and negative nighttime relationship between M and a_{cld} on some days

M and RH_{max} together explain cloud-base cloudiness very well

$$M = a_{co} \cdot w_{co}$$



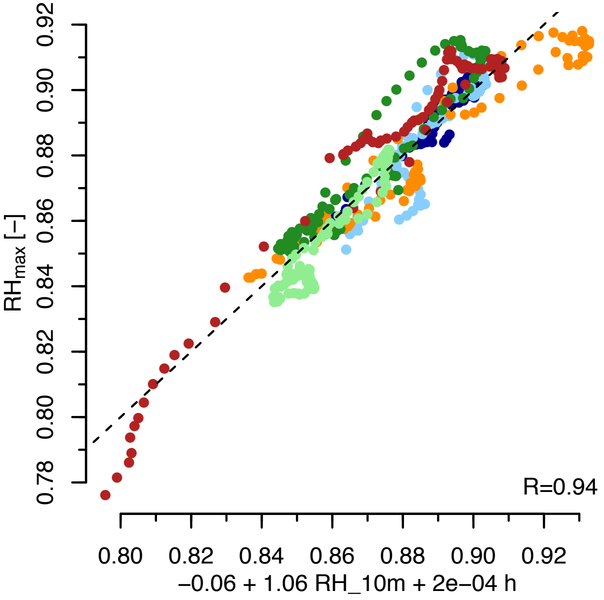
> Maximum relative humidity at mixed-layer top (RH_{max}) important additional control

> From mass budget perspective, M controlled by entrainment rate and large-scale vertical velocity

(Vogel, Bony, Stevens, in review)

> What controls RH_{max}?

RH_{max} controlled by surface RH and sub-cloud layer depth (h)



> Sub-cloud layer thus well mixed!

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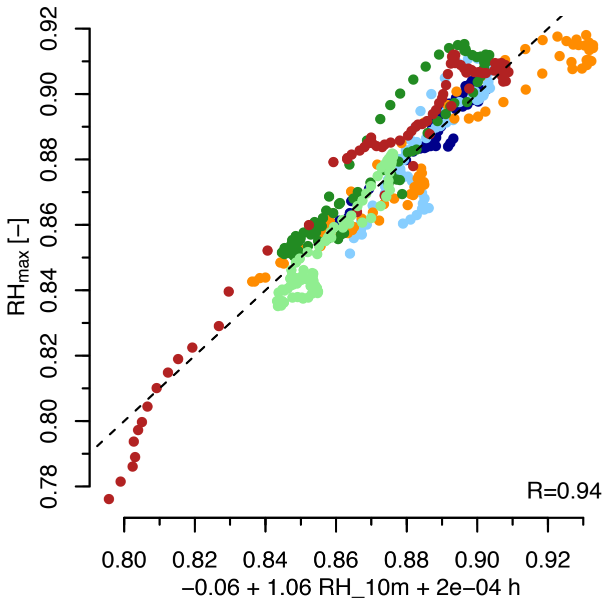

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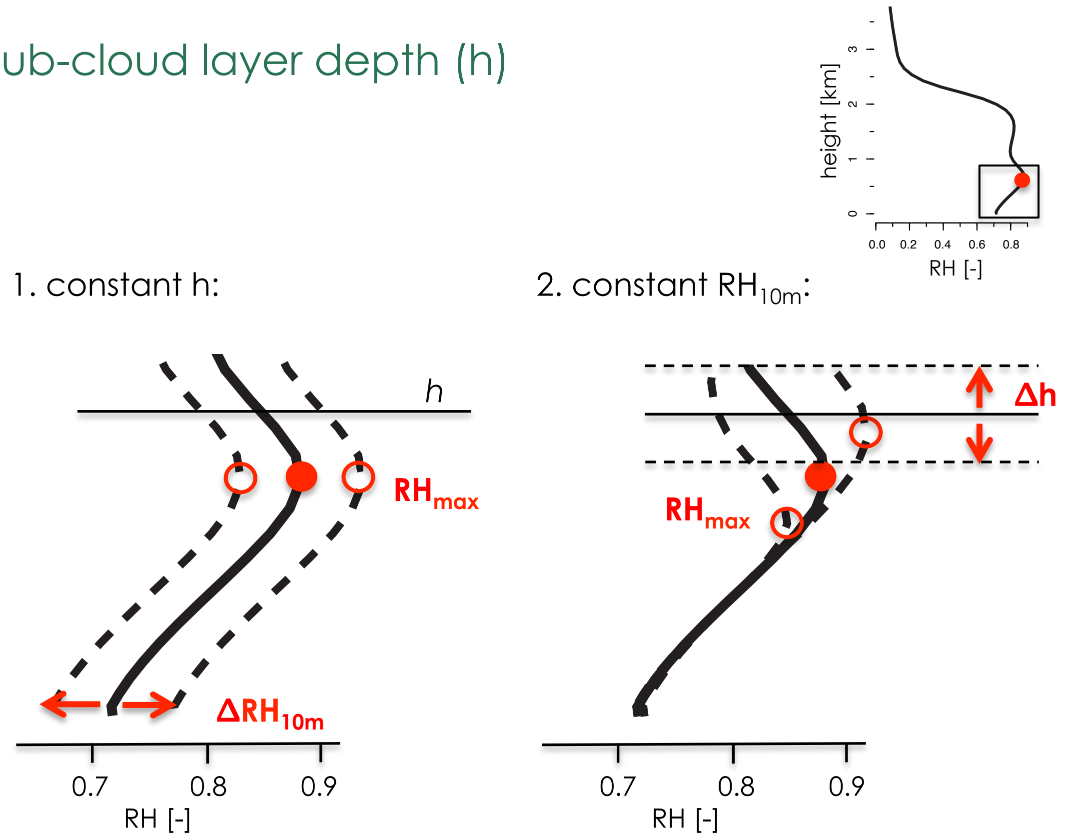

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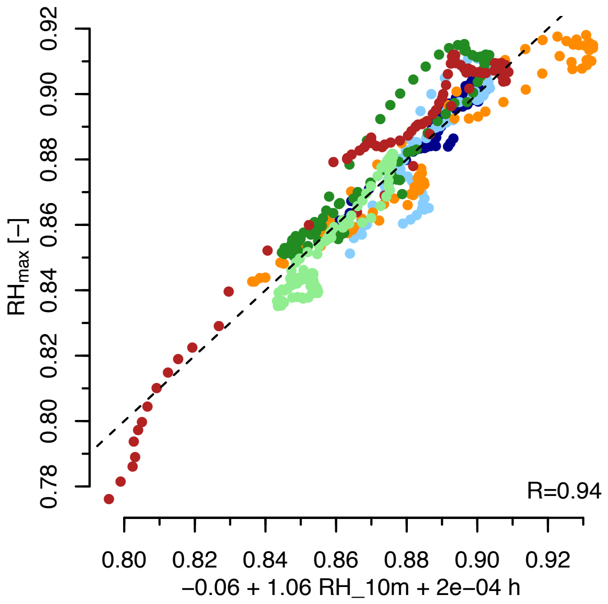
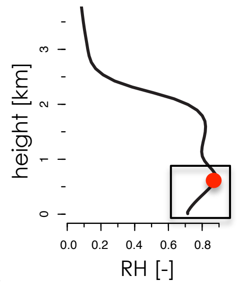
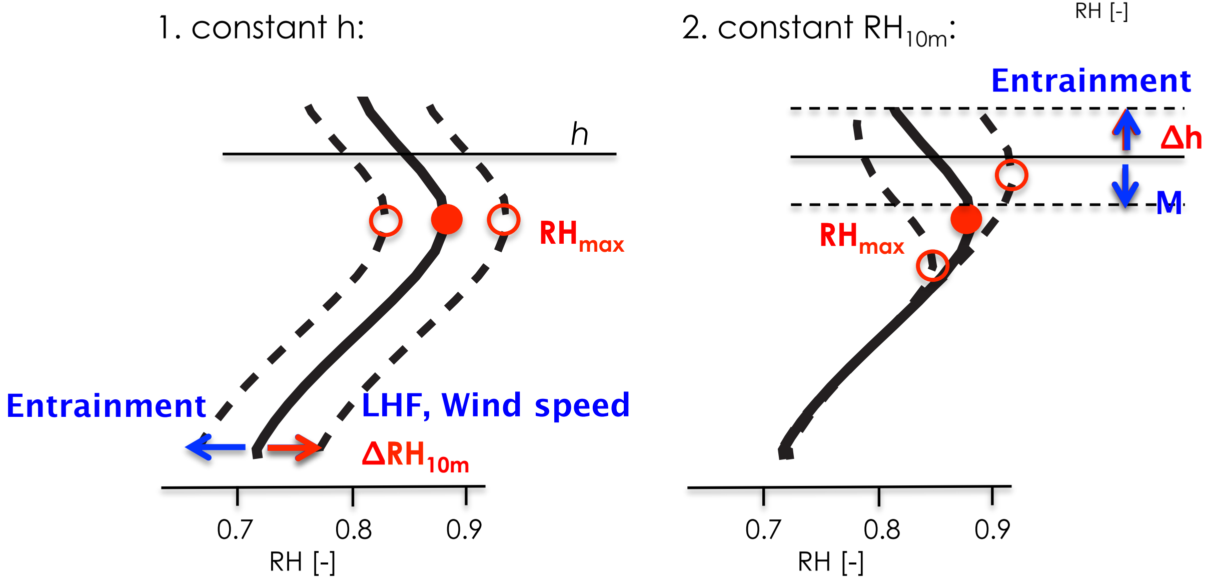






> Sub-cloud layer thus well mixed!

> Cumulus valve: Decrease in *h* in response to increase in *M* reduces RH_{max} and cloudiness, which reduces *M*

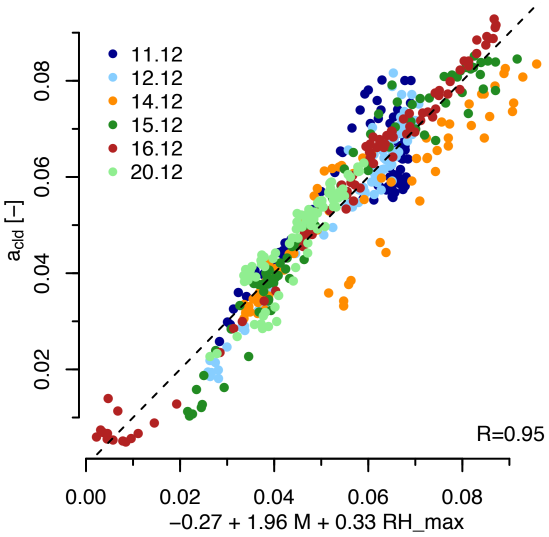
> GCMs tend not to resolve variations in *h* and unphysically compensate the increasing *M* by entrainment

Summary

> Combination of M and RH_{max} explains cloud-base cloudiness very well (R=0.95)

> M controlled by entrainment rate and large-scale vertical velocity *(Vogel, Bony, Stevens, in review)*

> RH_{max} controlled by surface RH and sub-cloud layer depth



How to think about the cumulus valve mechanism?

Coupling between mass flux and RH_{max} through mass budget crucial for capturing cloud response

>> to be tested during the EUREC⁴A campaign <<